Internal Cryogenics & Ullage

David Montanari

LBNC Review

18-21 February 2018

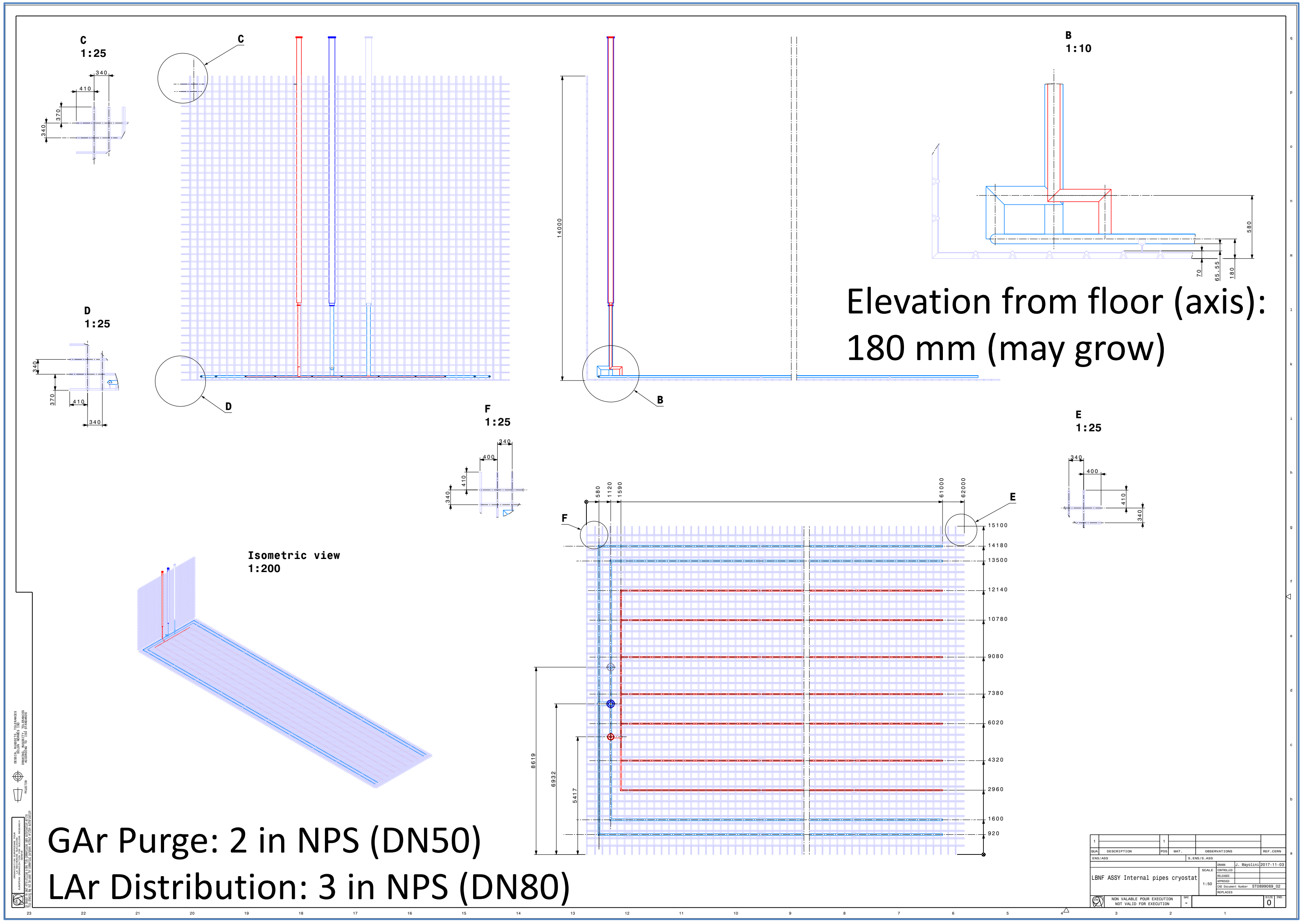
Thanks to

- Mark Adamowski (Fermilab).
- Jean-Baptiste Mayolini (CERN).
- Aurélien Diaz (CERN).
- Jack Fowler (Duke University).
- Kevin Haaf (Fermilab).
- Adrien Parchet (CERN).
- Erik Voirin (Fermilab).

Outline

- Internal Piping.
- Ullage considerations.
- Next Steps.

Internal Cryogenics Layout

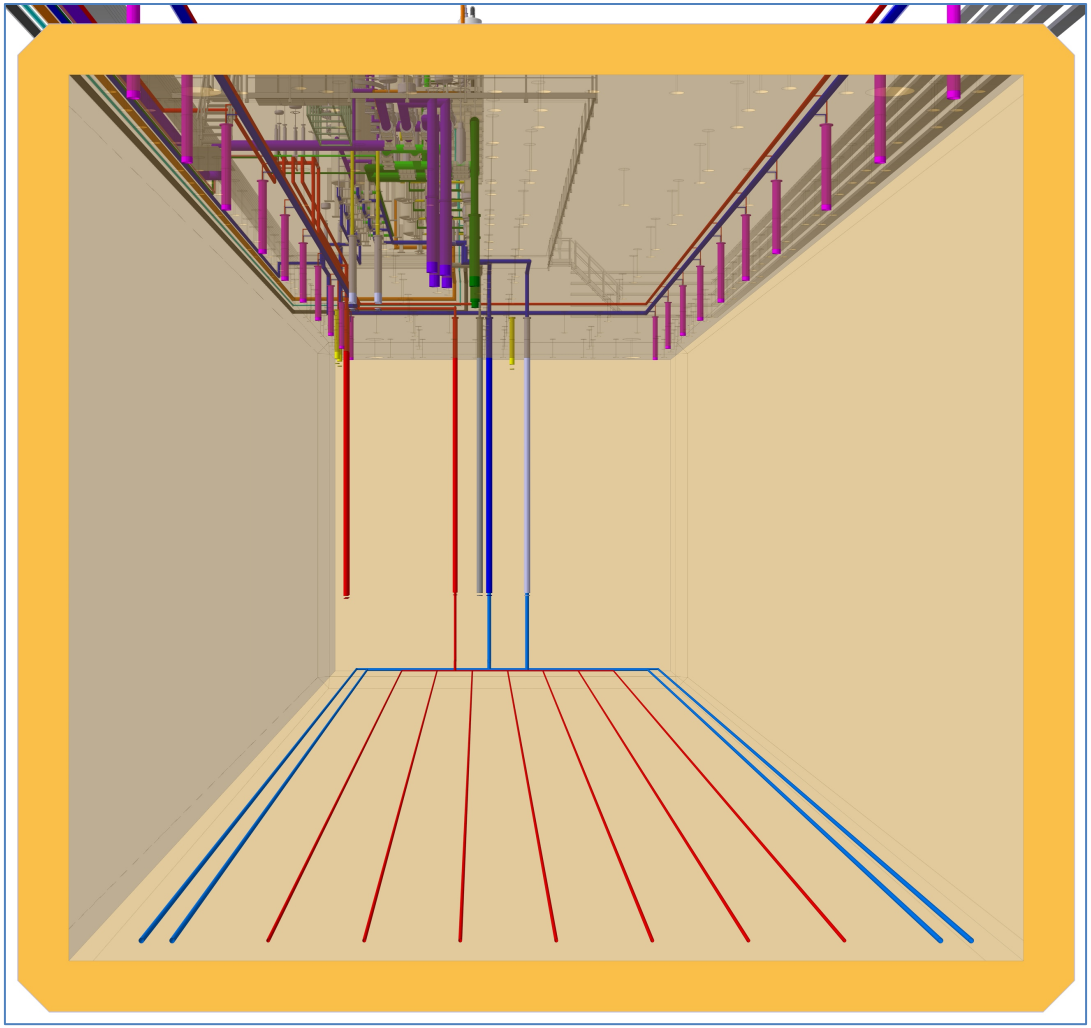


Elevation from floor (axis): 180 mm (may grow)

GAr Purge: 2 in NPS (DN50)

LAr Distribution: 3 in NPS (DN80)

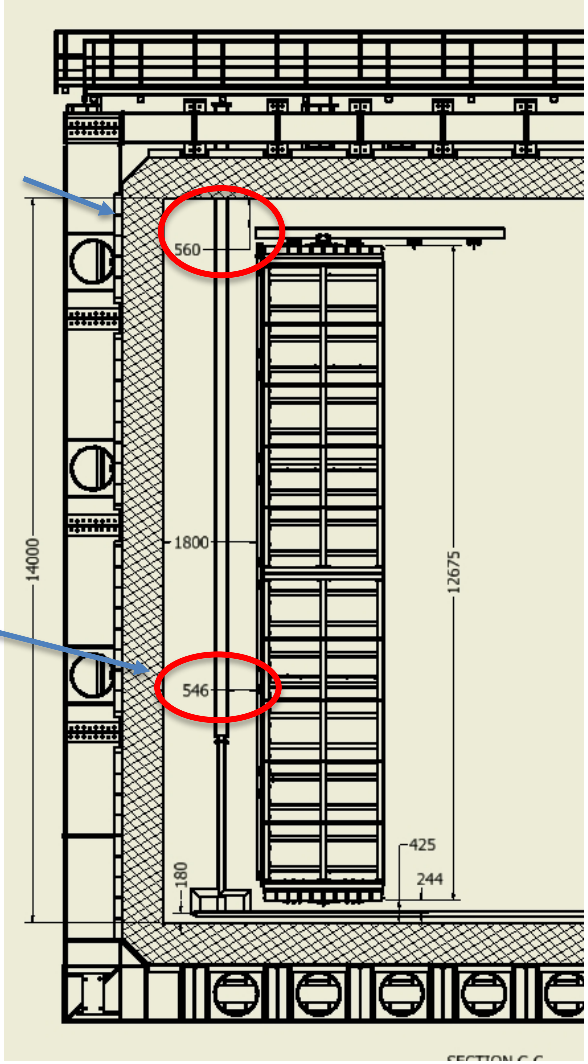
Iso View



Internal Cryogenics occupied space (current) – Top & Side

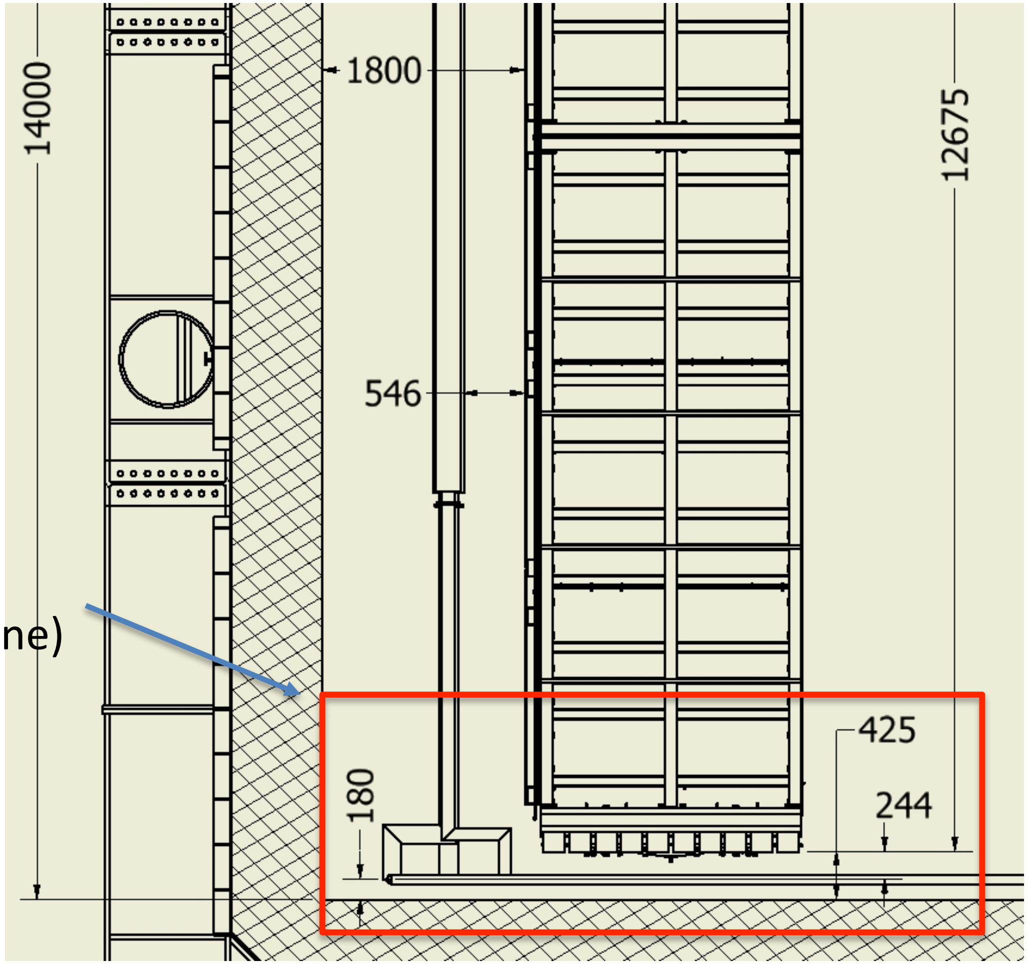
Top clearance:
- 560 mm (top of DDS beam to membrane)

Side clearance:
- 546 mm (pipe to detector)



Internal Cryogenics occupied space (current) – Bottom

Bottom clearance:
- 244 mm (CL pipe to cold electronics)
- 425 mm (cold electronics to membrane)
- 180 mm (CL pipe to membrane)



Internal Cryogenics Considerations

- Horizontal and vertical runs are too long for supports ProtoDUNE-style.
  - Horizontal ones would need to jump from one “square” to the other during cooldown and warmup.
  - Vertical ones need additional features to compensate the thrust force.
- Kevin H working on options to address these:
  - May (or may not) require more vertical clearance under the detector.
  - May (or may not) use some of the current 560 mm clearance. Is it ok?
- Pipes not directly under APAs/CPAs, but what about field cage? Can we get closer to it?
- Will update the 3D model of the internal cryogenics as needed.

Ullage considerations (at Operating Pressure)

- Current ullage is 5.7%: **800 mm** (LAr level 13.2 m).
- We already agreed to lower it to 5%, which is 700 mm (LAr level 13.3 m).
- Value is comfortable for operations and meet the minimum safety requirements of EN 14620. Can we lower it even further?
- Requirements:
  - Good engineering practice from EN 14620 requires a minimum ullage (freeboard) over the full pressure range.
  - Need to satisfy the seismic sloshing wave protection.
  - Need stability of operations.
- We would prefer to keep at least 4% ullage: **560 mm** (LAr level 13.44 m).
- With 700 mm ullage the LAr amount increases by 0.72% and the cost by $150k (each cryostat).
- With 550 mm ullage the LAr amount increases by 1.76% and the cost by $365k (each cryostat).
- If the pressure decreases (from 130 mBarg), the LAr level decreases, down 40 mm at atmospheric pressure.

Next Steps

- Continue to work on the thermal compensation of the internal cryo to verify vertical/horizontal clearance between the pipes and the detector.
- Identify the correct vertical position of the detector.
- Update 3D models, drawings, etc. as needed.

Thanks

Backup slides

Details calcs

Current situation (Feb 16, 2018)

Prepared by: David Montanari
Date: 16-Feb-18
Revision: 1

17,165,040 Kg LAr each cryostat (from LN2 Refrigeration table)
20,605,500 $ LAr First cryostat (from schedule)

						Ullage Option 1				**Ullage Option 2**				**Ullage Option 3**			
LAr level	**Ullage**		**Pressure**			**Ullage**		**LAr Increase**	**Cost Increase**	**Ullage**		**LAr Increase**	**Cost Increase**	**Ullage**		**% LAr Increase**	**Cost Increase**
m	*m*	*%*		mBarg		*m*	*%*	*%*	*USD*	*m*	*%*	*%*	*USD*	*m*		*%*	*USD*
13.163	0.837	5.98%	Fill P	50		0.742				0.523				0.602			
13.204	0.796	5.69%	Operating P	130		0.700	5%	0.72%	$ 148,638	0.480	3%	2.34%	$ 481,196	**0.560**	**4%**	**1.76%**	**$ 361,730**
13.136	0.864	6.17%	P_Atm	0		0.769				0.55				s			

Input values
(h-ullage_2)*rho_2=(h-ullage_1)*rho_1

Details calcs (from Mark A)

LBNF LAr Expansion Analysis to Determine Minimum Ullage

Pressure (MPa-g)	Pressure MPa-abs	Temp. (K)	LAr density kg/m3	LAr depth (m)	change in Ullage %	Ullage (mm)	
0.0000	0.10066	87.2	1395.8	13.450	-5.0%	**550**	**Min Ullage**
0.0050	0.10566	87.7	1392.9	13.477	0.0%	523	**Fill Pressure**
0.0100	0.11066	88.1	1390.2	13.504	4.8%	496	
0.0130	0.11366	88.4	1388.6	13.519	7.7%	481	**Operating Pressure**
0.0150	0.11566	88.6	1387.5	13.530	9.6%	470	
0.0200	0.12066	89.0	1384.9	13.555	14.1%	445	
0.0250	0.12566	89.4	1382.4	13.579	18.6%	421	
0.0300	0.13066	89.8	1380.0	13.603	23.0%	397	
0.0350	0.13566	90.2	1377.6	13.627	27.2%	373	**Design Pressure**
0.0385	0.13916	90.4	1376.0	13.643	30.2%	357	**Max Over Pressure - all relief scenarios**

Good engineering practice from EN-14620 requires a minimum of 300 mm of ullage (freeboard) space. This 300 mm can be counted as being part of the ullage space needed for seismic sloshing wave protection. This 300 mm satisfies the seismic sloshing wave protection needed for LBNF. Ref: "Structural assessment of the LBNF warm structure", presented at the LBNF Cryostat design review, August 21-22, 2017, EDMS: 183257.

This table starts with the liquid fill at 50 mbarg operating pressure and looks at the LAr expansion over the cryostat operating pressure range and calculates the change in ullage space. The fill LAr was set to a value that provides the 300 mm design safety cushion with an instrument error allowance (0.5% of range, 70 mm) over the whole operating pressure range. Above the design pressure the ullage could be below 300 mm due to instrument error. Since this occurs outside of the dessign pressure range , it is not a concern.

Based on this analysis the minimum design ullage is 550 mm and the target LAr fill level at 50 mbarg is 13.478 m. Smaller ullage space is only allowed due to LAr expansion as indicated in the above table.

Prepared by: Mark Adamowski rev: 2018-02-14

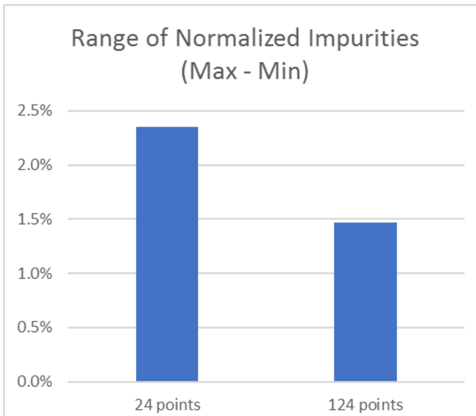
CFD update

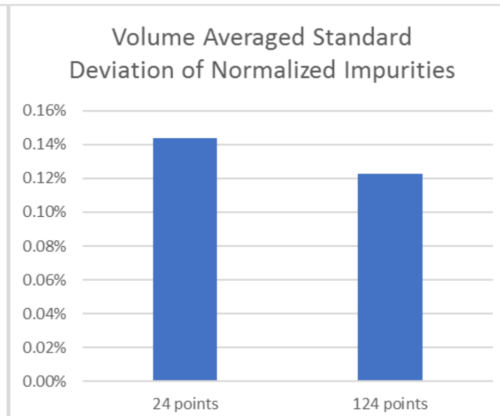
- Several CFD simulations have been performed to identify the optimal location of the LAr return pipes in the cryostat. Goal was to identify the configuration that optimizes the uniformity of the LAr inside the cryostat.
- Highlights:
  - LAr pumps not needed at each end of cryostat. One side only enough.
  - LAr suction line can be at any height (currently as low as possible to start the purification of the bulk of the LAr as soon as the NPSH is reached and the removal of the LAr at the end of the life of the experiment.
  - Can use two LAr return pipes, as long as the LAr is distributed through several points along the length of the cryostat (from 24 to 124 points).
- Must support 1-4 LAr circulation pumps running.

Results Comparison

(Arbitrary normalized value)

Discharge Flow Location	# of Pumps Circulating	Minimum Normalized Impurities	Maximum Normalized Impurities	Range of Impurities (Max-Min)	STD DEV Normalized Impurities	Ave Velocity	Minimum Lifetime	Maximum Lifetime	Lifetime Range	Suction Lifetime	Average Lifetime
		[-]	[-]	[%]	[%]	[mm/s]	[us]	[us]	[us]	[us]	[us]
24 points	1	0.98615	1.0097	2.4%	0.14%	6.77413	2974	3045	71	3000	3003
124 points	1	0.993725	1.0084	1.5%	0.12%	6.73984	2976	3020	44	3000	3001





Compare to Discharge Flow at only 1 end: 35x higher Standard Deviation

Discharge Flow Location	# of Pumps Circulating	Minimum Normalized Impurities	Maximum Normalized Impurities	Range of Impurities (Max-Min)	STD DEV Normalized Impurities	Ave Velocity	Minimum Lifetime	Maximum Lifetime	Lifetime Range	Suction Lifetime	Average Lifetime
		[-]	[-]	[%]	[%]	[mm/s]	[us]	[us]	[us]	[us]	[us]
Far End	1	0.9356	1.0574	12.2%	4.24%	7.6674	2967	3354	386	3000	3138

Fermilab